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CASE STUDY

The environmental impact of engineering education in Australia

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Abstract
Background, aim, and scope The process of producing a graduate is a complex one involving major effort usually by large institutions such as universities. The Faculty of Engineering and Surveying at the University of Southern Queensland, Australia produces several hundred engineering and spatial science graduates each year using both on-campus and external modes of study. The purpose of this study is to determine the major causes of environmental impact in this process with a view to targeting areas where improvements may be made.
Materials and methods An inventory of all major inputs to and outputs from the faculty was compiled from a mixture of measurements, real data, and financial data for the calendar year 2006. Data for graduate output were also compiled. These data were then assessed using SimaPro software, mainly Australian data and predominantly the Eco-indicator 99 (E) method of impact assessment.
Results The analysis shows that environmental impacts are many and varied as might be expected from a complex operation like a university. However, energy inputs in the form of electricity from black coal, staff and student travel and the embodied impact of buildings were dominant.
Discussion The results obtained may point the way towards future consideration of areas where environmental impact might be reduced by changes in institution strategies such as the way external students are taught and the way the electricity usage in our buildings is managed.
Conclusions The environmental impact of undergraduate education is complex and involves many different areas of activity. However, the use of energy in various forms is of major significance in this impact.
Recommendations and perspectives It is recommended that university managers consider the results presented in this paper and use them as a starting point in developing strategies to reduce the impact of their institutions.

Keywords Buildings · Energy · Engineering education · Environmental impact · External student · Graduate output · Input–output · Laboratory operations · On-campus student · Travel · University operations

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1 Background, aim, and scope

While education processes now have extensive accounting systems for financial inputs and outputs, such accounting does not appear to have been done much for environmental impact inputs and outputs. Engineering education necessarily involves aspects of sustainability because of the fundamental role engineering professionals play in shaping resource use for our communities. In more general ways, engineering professionals and students are being encouraged to consider the environmental impacts of systems they design and build; see, for example, Hersh (2000), Martin and Schinzinger (2005), and Johnston et al. (1999). It seems timely therefore that the environmental impact of the process of education itself be also considered. Such analyses might well inform decisions about what kind of education processes are preferred, particularly now when education can be conducted in many ways ranging from traditional on-campus full-time study through to fully external study using communication and other technologies. The Environmental Management for Sustainable Universities Conference several years ago (Hamer 2002)

considered some of the relevant issues but not at the level of detail proposed in the present study.

2 Engineering education at the University of Southern Queensland

2.1 External and on-campus students

The University of Southern Queensland (USQ) in Australia is a small regional university with a 40-year history. It specializes in the provision of external education with about 80% of its 25,000 annual students studying from home and rarely visiting the central campus. Course material is provided by means of printed notes and a range of other media. On-line activities are also a major part of the management and operation of teaching and learning. In parallel with the external teaching activities, there are conventional on-campus classes.

The Faculty of Engineering and Surveying (FOES) is one of five faculties within the university and accounts for about 10% of its teaching activities. A breakdown of USQ and FOES student statistics is given in Table 1 for the calendar year 2006, and an indication of the enrolments and equivalent full-time enrolments is given in Fig. 1. The faculty differs from some other faculties by the need to provide practical activities to students which is partly achieved by a requirement to attend campus for about 1 week per calendar year.

Programs run by the faculty are predominantly in the areas of civil engineering, electrical engineering, mechanical engineering, and spatial science, with many smaller and related sub-areas. Awards are available over the range from Associate Degree to PhD but are statistically dominated by the following three:

- Associate Degree, 2-year equivalent full-time study
- Bachelor of engineering technology, 3-year equivalent full-time study
- Bachelor of engineering, 4-year equivalent full-time study

External students live and study in a wide range of locations both across Australia and internationally. Most Australian students, however, live in the State of Queensland which covers a large area spanning well over 2,000 km in the north–south direction and similar distances in the east–west direction. Most international students have come from the Southeast Asian area, predominantly Singapore, Malaysia, and Hong Kong. Consequent on this geographical distribution is a relatively large amount of travel for students who must attend USQ campus for practical work and for some staff who travel to provide limited face-to-face assistance in some centers such as Singapore.

Staff, academic, administrative, and other personnel are mainly based at the Toowoomba campus from where most teaching, research and administration is done. Funding of University operations comes largely from the Australian Government for Australian students and from fees paid by international students.

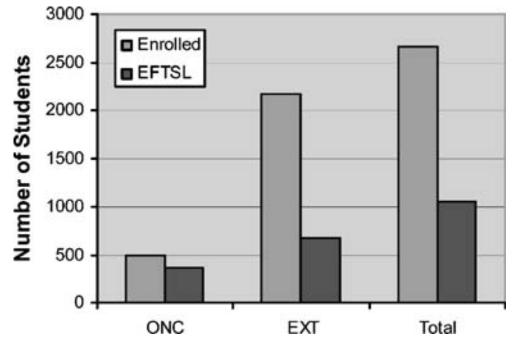

Fig. 1 Student enrolments and equivalent full-time student loads in the Faculty of Engineering and Surveying by study mode in 2006

Table 1 Overall full-time equivalent student load (EFTSL) statistics for the University of Southern Queensland and the Faculty of Engineering and Surveying in 2006

EFTSL	USQ	FOES	FOES as % of USQ
External students	7,929	687	8.7
On-campus students	4,320	365	8.4
Total	12,249	1,052	8.6

2.2 Graduates

The number of graduates produced by the faculty in 2006 in various categories is given in Table 2. The results of this study assume that a similar number of graduates is produced every year because generally student numbers have been approximately steady for several years. Hence, the environmental inputs and outputs of the year 2006 are attributed to this number of graduates. For some university awards, a significant number of students enter with substantial exemptions due to study completed previously. The quantity of exemptions has been estimated from personal knowledge, and a figure for the fraction of exemptions not due to faculty effort was determined. The effort expended by the faculty and hence, it is assumed, the environmental impact, is shown in Fig. 2.

3 The environmental impact of the education of engineering graduates

3.1 Using life cycle analysis

The method used to assess the environmental impact was life cycle assessment (LCA) because this methodology was

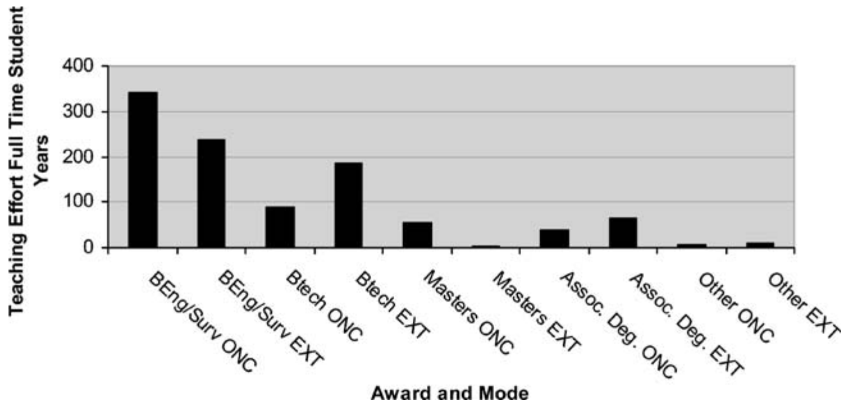

Fig. 2 Teaching effort expended by the faculty for most categories of student award and mode

familiar to the author, and commercial software gave access to extensive databases through which to make judgments. The databases include several internationally accepted methods for assessing impact in areas such as human health and resource use. This methodology allows the relative magnitudes of impact of various parts of a process to be compared, thus informing decisions about the design of those processes. Judgments can then be made about where best to place future efforts to reduce environmental impact.

Firstly, values for all major physical inputs and outputs for a year of operation of the Faculty of Engineering and Surveying were assembled into an inventory. These data were then entered into software called SimaPro (Pre Consultants 2008) which connects it with data for the environmentally relevant inputs and outputs of many different materials and processes, collected from industry around the world. A method of environmental impact assessment is then selected and calculations performed. These calculations are based on correlations between the inputs and outputs and known impacts such as the health impacts of sulfur dioxide or the effect on wildlife of sewage in water. For most of this study, the impact method Eco-indicator 99 (E) Australian Substances was used since it has been found to give results comparable to several other such methods.

This LCA methodology has some evident limitations, but it is the best available at the current time and is recognized as being a useful tool. Some limitations are:

The environmental impact is assumed to be global or regional, ignoring the fact that impact may be greater or lesser in different locations such as near a thermal power station or at some distance from it.
While there are now extensive Australian data, much data are European in origin.
Data used depend on availability, and there are no data for many industries and products, partly because of commercial confidentiality concerns.
A university is a complex organization with its own levels of confidentiality, making it difficult to obtain precise data for all inputs and outputs.

A consequence of the above is that this study focuses on the operations of a single faculty and accounts for inputs

Table 2 Number of graduates produced by the faculty in 2006, including the fraction of graduate impact not due to the faculty activity

Degree program	Duration in full-time equivalent years	Number of graduates		Fraction of degree not contributed by the faculty	Total full-time years effort put into graduates by faculty	
		On-campus	External		On-campus	External
Double degree	5	13	1	0.2	52	4
Associate Degree	2	19	33	0	38	66
Bachelor of Engineering or Surveying Technology	3	42	79	0.3	88	185
Bachelor of Engineering or Surveying	4	80	65	0.1	288	234
Master of Engineering Technology	2	30	28	2	56	4
Graduate Certificate	0.5	5	7	0	3	1
Graduate Diploma	1	4	8	0	4	8
Total		193	221		529	502

and outputs due to other parts of the University such as administration, management, and the library only via financial data and models from other sources.

Data about the operation of the Faculty of Engineering and Surveying were collected from within the university for the calendar year 2006 using a variety of methods. In this process, many judgments were made about allocation of inputs and outputs to the faculty from within those of the whole university as outlined below:

(a) The operation of the faculty in the context of the University as a whole is complex, involving numerous activities managed by many different groups of people. The University allocates funding initially to overall service providers such as the library and the group responsible for buildings and other facilities. Financial data about the cost of providing each of these services were used to allocate a proportion of 8.6% to the faculty operations based on the proportion of students in the faculty as given in Table 1 above.
(b) Not all teaching is done by the faculty, with for example, mathematics being taught by the Faculty of Sciences. In addition, some teaching is done by the faculty for other university programs. Consequently, FOES activities are responsible for only 85% of its student outcomes. To account for this incompleteness, all faculty environmental impacts have been scaled up by a factor of 1.18 (1/0.85). This decision assumes that the impact of other faculties is of similar magnitude to that of FOES.
(c) As is normal in universities, most academic staff spend considerable time on research which is not related directly to student outcomes. Within FOES, research accounts for about 18% of academic staff workloads and about 14% of total staff workloads. However, the view was taken that such research activity is an essential part of the student outcomes at university because it informs teaching and learning, and so its environmental impacts have been included in the analysis where possible. However, no measure of research output has been included.
(d) Several aspects of environmental impact were estimated from the author's knowledge of the faculty's operations or student patterns of behavior, such as daily travel or computer use. Estimates took into account the difference between full-time students and external, normally part-time students by normalizing all data to a full-time equivalent. The outcomes of these estimates are given in the paragraphs which follow.

Computer use It was assumed that students needed to use a computer for 10 h/week for 30 weeks of the years for study and that a typical computer used electrical energy at a rate of 60 W. It was also assumed that this electricity was generated in eastern Australia by a coal-fired power station. It was further estimated that study would account for 10% of the total computer uses and the environmental cost of production of the computer. This assumption was in the context that computers are typically replaced every 5 years due to technological improvements.

Student travel On-campus students were each assumed to travel by individual private car an average of 3 km per day for 4 days/week and 30 weeks of the years specifically for study. These assumptions were based on the geography of Toowoomba, typical student accommodation patterns, and the local transport services. The outcome of this estimate is given in Table 3. External students were assumed to travel by car an average of 10 km per semester to sit for examinations, etc.

In addition, external students must attend practical work courses for the equivalent of one trip per year full-time equivalent, and most international students attend two 1-week courses in two sequential weeks to minimize trips. Students who were enrolled in residential schools in 2006 were counted and allocated to broad geographical regions of Australia and the rest of the world as shown in Fig. 3. For students living within about 400 km of Towoomba, it was assumed that they traveled by car. For those further away, it was assumed they traveled by air to Brisbane and then by bus to Toowoomba. This gave the total distances traveled shown in Table 3.

Student consumables It was assumed that students typically spend \$50 on postage, \$40 on paper, pens, etc, and \$240 on textbooks per year.

Faculty equipment The faculty periodically spends considerable amounts of money on equipment, but the annual amount varies considerably from year to year. Consequently, an estimate has been made of average expenditure and type of equipment based on looking at expenditure over

Table 3 Estimates of student travel

Student and travel modes	Total distance (km)
On-campus daily car travel	131,400
On-campus student excursions by bus	440
External local car travel	13,740
External residential school car travel	123,020
Australian external residential air travel	328,888
International external residential school air travel	445,686
All external residential school bus travel	38,402

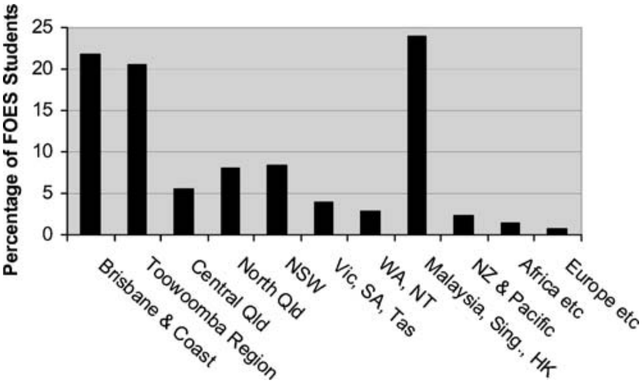

Fig. 3 Percentages of external students traveling to residential schools from various regions. *Qld* is the State of Queensland in which the university is situated, *NSW*, *Vic*, *SA*, *Tas*, *WA*, and *NT* are other states of Australia

several years. In addition, the environmental impact per year of the equipment purchased in the year of study has been divided by a factor related to the expected lifetime of the equipment, assumed to be 10 years. The factors used are given in Table 4.

Faculty buildings To account for the environmental impact of the buildings involved, the floor areas of FOES and USQ buildings were estimated and compared to published data by Scheuer et al. (2003) who give a detailed inventory of a new university building in the USA. The data from Scheuer et al. (2003) were then scaled in proportion to the areas of that building and those at USQ with mainly Australian data being used for the impact of components such as concrete. A lifetime of the buildings of 70 years was assumed to allow for the life of the main building structure, possibly greater than 70 years, and the likely refurbishment of interiors at more frequent intervals.

Electric energy Measurements were made of energy use in the primary building housing the faculty by placing a recording power meter on the switchboard cables for periods of at least 24 h and over some weekends over the year April 2007 to April 2008. This was done at several different times of the year and in several different locations. Average energy consumption on a typical working day and weekend day were then estimated by visual averaging of demand over periods of different demand such as day/night. This data were then scaled up according to the number of working and non-working days in a year. Confirmation of the overall results was then obtained by cross-checking the result with overall energy consumption as recorded by the kWh meter on the switchboard.

The procedure above allowed the separation of energy use by the following aspects of the building operation: air conditioning, lift, all other uses such as lighting, computers, and student laboratories. Final results for the energy consumption of the building over a year are given in Table 5.

Staff travel Full details were available for staff travel on faculty business to attend conferences, consult industry colleagues, attend meetings, etc.

Other inventory items Data for a small number of other inputs such as postage and water usage were available. All the other significant inputs to the operations of the faculty were estimated using financial data and accounted for environmentally by using national input–output tables from other developed countries which were available in the databases.

Table 4 Assumed lifetime of equipment

Equipment type	Expected life time (years)	Factor applied to equipment to account for lifetime and buying pattern
Vehicles	5	0.2
Computing equipment	4	0.25
Laboratory equipment	10	0.3
Furniture	10	0.2
Software	5	0.2
Buildings	70	0.0143

4 Results

4.1 Attribution to faculty operations

Initially, an analysis was done of the operations of the faculty alone because of the less well-known inputs and outputs of the broader University components as discussed above. A summary of this faculty assessment is given in Table 6 where it can be seen that, as perhaps expected, the operational sources of significant environmental impact are numerous and include such items as electricity use, staff and student travel, faculty laboratory operations, faculty buildings, and printing. Because of this complexity, the results are analyzed further below.

4.2 Causes of impacts

While the data above give a clear indication of what the operational causes of the impact are, it is not always clear just what the root causes are. Some of the root causes of impacts are shown in Figs. 4, 5, 6, and 7 to give an indication of where action might be taken to ameliorate these impacts. The units used in these figures are the standard ones used for the relevant impact.

Table 5 Energy use in a year by the Faculty of Engineering and Surveying

Building feature	Use	Total energy consumption (kWh)	Percentage of total
Level 1	Laboratories and 5 staff	50,120	4.4
Level 2	Laboratories and 6 staff	41,750	3.6
Level 3	Computer laboratories, 37 staff, academics and postgraduates	132,980	11.6
Level 4	Majority of staff offices, administration, management and academics, ~62 staff	99,490	8.7
Air conditioning		597,400	52.1
Lift	Lift between floors 1 and 4	200,000	17.4
Other FOES buildings	Mechanical workshop, civil and water laboratories	24,820	2.2
Total		1,146,560	100

4.3 The impact of university functions

The appropriate proportion of general University data attributable to the faculty operations were then added to the data for inputs and outputs of the faculty to determine what additional impact they might have. As stated above, these data were almost entirely financial and based on input–output tables from other countries and so are considered to be less likely to be correct than the data used for analysis of the faculty operations alone. Table 7 gives the total scores on the same criteria as in Table 6 for both the faculty alone and for the faculty plus University operations, together with the percentage increase due to the addition of the University data.

The data in Table 7 suggest that the impacts due to the faculty are dominant in some cases and less so in others, with that due to the addition of general University operations adding from a few percent to at most 105%. This is broadly consistent with the fact that faculty funding accounts for somewhat less than 50% of overall university funding under the management model used. However, it is also true that much of the faculty impacts come from normal staff activities such as buildings and electric energy which are likely to be similar in other parts of the University. Areas where less impact might, however, be expected from the University operations are staff travel, since academic staff probably travel more than administra-

Table 6 Annual environmental impact of faculty operations alone

	Climate change (DALY)	Respiratory organics (DALY X 10e-3)	Respiratory inorganics (DALY)	Ecotoxicity (PAF x 10e3)	Acidification-eutrophication (PDF X 10e3)	Fossil fuels (MJ surplus X 10e3)	Minerals (MJ surplus)
Office consumption, etc.	0.046	1.05	0.20	72	5.8	55.1	57.8
Advertising and printing	0.039	0.92	0.15	15.2	5.1	17.9	0.87
Computers and phone	0.0083	0.14	0.032	58.4	0.89	29.0	56.5
Building and maint.	0.0027	0.052	0.013	3.9	0.38	2.0	5.0
Buildings	0.013	0.044	0.073	6.9	1.54	54.6	32,500
Laboratory operations	0.029	0.40	0.12	401	2.6	185	640
Energy air condit.	0.127	0.044	0.59	9.5	20.4	427	192
Energy lift	0.043	0.015	0.20	3.2	6.83	143	64.3
Energy remainder	0.075	0.026	0.34	5.6	11.9	250	112
Staff travel	0.067	0.81	0.26	52.6	11.0	240	0.55
Student travel	0.068	0.89	0.19	38.7	9.8	327	76
Total	0.52	4.39	2.16	667	76.2	1,730	33,700

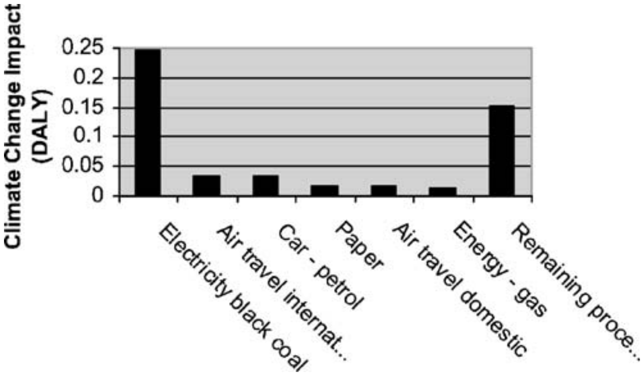

Fig. 4 Underlying causes of environmental impact of the faculty on climate change

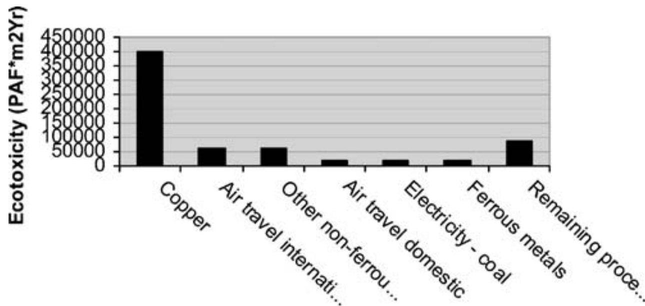

Fig. 6 Underlying causes of environmental impact of the faculty on ecotoxicity

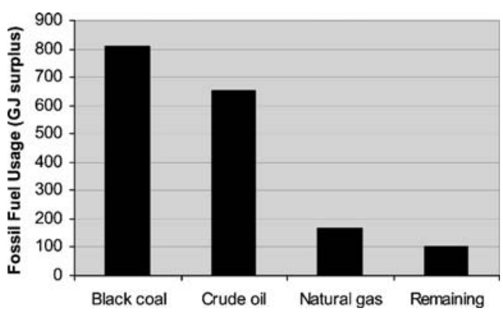

Fig. 5 Underlying causes of environmental impact of the faculty on fossil fuel usage

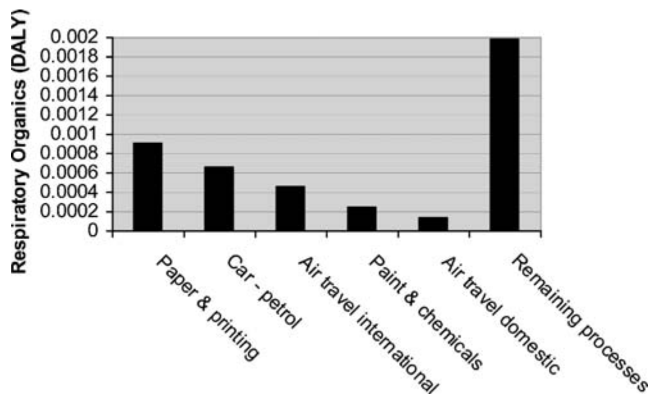

Fig. 7 Underlying causes of environmental impact of the faculty on the production of respiratory organics

Table 7 Comparison of environmental impact due to faculty and faculty plus university operations

	Climate change (DALY)	Respiratory organics(DALY X 10e-3)	Respiratory inorganics (DALY)	Ecotoxicity (PAF x 10e3)	Acidification-eutrophication (PDF X 10e3)	Fossil fuels (MJ surplus X 10e3)	Minerals (MJ surplus)
Total due to faculty	0.52	4.39	2.16	667	76.2	1,730	33,700
Total due to faculty plus university	0.87	9.02	3.29	769	115	1,750	45,900
Percentage increase	67	105	52	15	51	1.2	36

Table 8 Environmental performance indicators

Indicator	U of Lisbon total	U of Lisbon per graduate	Faculty of Engineering and Surveying total	Faculty of Engineering and Surveying per graduate
Water use (m^3)	136,000	97	Confidential	~26
Energy use (kWh)	6.05E6	4,321	76,944	2,056
Greenhouse gas emissions (kg CO_2 eq.)	106E3	7,571	4090E3	15,853

tive staff and student travel because the other sections of the university do not have students.

5 Discussion

5.1 Areas for improvement

Overall, the environmental impact of the faculty and hence of the production of engineering graduates comes from many different aspects of its operations. This makes it difficult to target one or two major areas for improvement but rather suggests the need for a strategy to identify areas where improvements may be made. The data in Table 6 would be a useful starting point from which to proceed. Possible areas to target would appear to be electricity usage in the faculty buildings and staff travel. Student travel could also be questioned since it is based on a particular model of external education and the need for residential schools to give students practical experience.

In this analysis, it has not been possible to separate the impact of the two teaching modes of on-campus and external, apart from their travel, because students in both categories are often treated together by administrative and teaching staff, particularly since on-line teaching is now a common experience for both. In addition to this, many nominally on-campus students are now studying part time because of the need to seek paid employment.

5.2 Comparative performance

Published results for an environmental performance analysis of a university system are rare, with the only such study found being Fouto et al. (2002). This study was of a campus at the University of Lisbon in Portugal and covered only selected criteria. However, it is useful to compare the reported performance with those of the present study.

The University of Lisbon had a reported student population of 5,600 full-time students in 2000, the year of the study. If a broad figure of an average of 4 years of study to produce a graduate is assumed, that gives an annual graduate output of 1,400. By comparison, the Faculty of Engineering and Surveying at USQ has a large range of program durations and the complexity of a majority of external students. However, broad figures are as reported above that student effort is about 1,031 effective full-time student study years in the calendar year 2006. If again an average program duration of 4 years is assumed, this gives an annual graduate output of 258. Table 8 gives the values of the environmental performance indicators reported by Fouto et al. (2002) and those for the Faculty of Engineering and Surveying on a per graduate output basis.

There are several large uncertainties in the data above. Significant among these is the fact that at FOES, most students are not on campus and so do not directly contribute to water and energy use, etc. However, their share of energy use and greenhouse gas emissions are partly accounted for by inclusion of staff effort, student travel, etc, so the comparison remains useful. On the basis of the data in Table 8, it seems that to produce a graduate at FOES requires significantly less water and energy than it does at the University of Lisbon but about twice as much greenhouse gas emission. These differences are to some extent explainable by the different climates and the larger distances involved in study in Australia.

6 Conclusions and recommendations

As a way of determining the significance of the results in a broader context, the data for the faculty operations were assessed using the Ecological Footprint method, yielding an overall result of 1.3 Ha per graduate. If this is compared to results from simple personal ecological footprint analyses for those living in the developed world (see for example Wackernagel et al. 2000), a typical figure of 4 to 5 Ha is obtained. Hence, it may tentatively be concluded that the process of undergraduate education for an individual has a significant additional impact of the order of 30%.

It is recommended that university managers consider the results presented in this paper and use them as a starting point in developing strategies to reduce the impact of their institutions.

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